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### **Process for Monitoring Function of an NO<sub>x</sub> Sensor**

#### **Arranged in an Exhaust Duct of an Internal Combustion Engine**

The invention relates to a process for monitoring the function of an NO<sub>x</sub> sensor arranged in an exhaust duct of an internal combustion engine, having the features named in the generic clause of Claim 1.

For reduction of a pollution emission of internal combustion engines, a known practice is to arrange suitable catalysts in the exhaust gas duct. In the catalysts, firstly, pollutants that can act as reducing agents, such as CO, HC or H<sub>2</sub>, may be oxidized by atmospheric oxygen, and secondly, NO<sub>x</sub> formed during a process of combustion in the engine may likewise be reduced to nitrogen on the catalysts with the aid of the reducing agents.

If the engine is in a lean mode more favorable to combustion, the proportion of oxygen in the air-fuel mixture is increased, and consequently a proportion of the reducing agents in the exhaust is decreased. In that case, of course, an adequate reaction of NO<sub>x</sub> is no longer ensured. As a remedy, an NO<sub>x</sub> reservoir is arranged in the exhaust duct, and it may be combined with the

catalysts to make an NOx storage catalyst. The NOx storage catalyst will absorb NOx either so long as an NOx desorption temperature is exceeded or until an NOx storage capacity is exhausted. Prior to that time, then, a change must take place into a regeneration mode with 1 to regenerate the NOx storage catalyst and prevent NOx emission.

It is known that a necessity of regeneration may be made dependent on an NOx concentration detected downstream from the NOx storage catalyst. The NOx concentration is detected by means of an NOx sensor. A disadvantage of this, however, is that in the presence of a malfunction of the NOx sensor, too high NOx emissions may occur, or an unnecessary added consumption may result from a premature regenerating measure.

The object of the invention is to detect such malfunctions of the NOx sensor in simple manner so that appropriate countermeasures may then be adopted if necessary.

According to the invention, this object is accomplished by the process for monitoring the functioning of the NOx sensor, having the features named in Claims 1 and 5. By

- (a) Determining an NOx mass absorbed by the NOx storage catalyst from a test signal of the NOx sensor within a period of diagnosis,
- (b) At the same time, in terms of a model of the NOx storage catalyst, calculating an absorbed NOx mass target, and
- (c) Comparing a ratio of the NOx mass to the NOx mass target (control value  $KW_n$ ) with a lower bound  $G_{nu}$  or an upper bound  $G_{no}$ ,

or by

- (a) Detecting a duration  $t_{mes}$  for a complete NOx regeneration of the NOx storage catalyst,
- (b) From a model of the NOx storage catalyst and a measured or calculated NOx loading condition, calculating a target duration  $t_{mod}$  for the NOx regeneration, and
- (c) Comparing a ratio of the duration  $t_{mes}$  to the target duration  $t_{mod}$  (control value  $KW_t$ ) with a lower bound  $G_{tw}$  or an upper bound  $G_{to}$ , the monitoring of the function of the NOx sensor can be accomplished in simple manner.

In a preferred embodiment of the process, upon transgression of the control value  $KW_n$  or  $KW_t$ , respectively, beyond the upper bounds  $G_{no}$ ,  $G_{to}$ , or upon transgression of the lower bounds  $G_{nu}$ ,  $G_{tu}$ , maintenance signals are generated. Then after occurrence of such a maintenance signal, the error can be corrected by suitable maintenance measures, or the NOx sensor can be replaced if necessary.

Further, it is advantageous to set the period of diagnosis to begin immediately after a complete NOx regeneration of the NOx storage catalyst and a change in the lean mode of the engine. Advantageously, the period of diagnosis will end after identification of a need to regenerate the NOx storage catalyst or upon a change in regeneration mode.

Monitoring of the function of the NOx sensor should preferably take place only when a very largely constant lean mode of operation of the engine has been

detected. In this way, the influences, difficult to allow for, of a dynamic operation of the engine, on the model of the storage catalyst, can be avoided.

Other preferred embodiments of the invention are given by the features named in the subsidiary claims.

The invention will now be illustrated in more detail in terms of an example with reference to the accompanying drawings, in which

Fig. 1 shows a schematic arrangement of an internal combustion engine having an NO<sub>x</sub> storage catalyst and an NO<sub>x</sub> sensor, and

Fig. 2 shows a block diagram of a monitoring of the function of the NO<sub>x</sub> sensor according to the example.

Fig. 1 shows an arrangement of an internal combustion engine 10 comprising, in an exhaust duct 12, a precatalyst 14 and an NO<sub>x</sub> storage catalyst 16. The precatalyst 14 and the NO<sub>x</sub> storage catalyst 16 serve to diminish a pollutant emission of the engine 10.

Ordinarily, the catalyst 14, 16 comprise components that make possible an oxidation of reducing agents formed, such as CO, HC or H<sub>2</sub>, by atmospheric oxygen. At least the NO<sub>x</sub> storage catalyst 16 comprises a catalyst component that makes possible a reduction of NO<sub>x</sub> likewise formed during a process of combustion of an air-fuel mixture, by means of the reducing agents. To be sure, if the engine 10 is in a lean mode, as a rule a proportion of the reducing agents in the exhaust will not suffice to afford a sufficiently high conversion of NO<sub>x</sub>. In lean mode, therefore, the NO<sub>x</sub> is absorbed as nitrate by a storage component of the NO<sub>x</sub> storage catalyst 16.

The absorption of the NO<sub>x</sub> can take place only until either an NO<sub>x</sub> desorption temperature is exceeded or an NO<sub>x</sub> storage capacity is exhausted. Before this point in time, therefore, a change must take place into a regeneration mode with  $\lambda \leq 1$  to make possible an NO<sub>x</sub> regeneration. In known manner, an NO<sub>x</sub> concentration or emission detected by the NO<sub>x</sub> sensor 18 may be the criterion for a need to regenerate. A corresponding test signal is passed on for example to an engine control instrument 20, is evaluated there, and used to control an operating mode of the engine 10.

Fig. 2 shows a block diagram with which a monitoring of the function of the NO<sub>x</sub> sensor 18 during dynamic operation of the engine 10 can take place according to this example. In a step S1, it is first detected whether a complete NO<sub>x</sub> regeneration of the NO<sub>x</sub> storage catalyst 16 has been carried out. If this is not the case, then the monitoring of the function of the sensor 18 is discontinued (step S2).

At the beginning of the lean mode (step S3), a determination of an NO<sub>x</sub> mass incorporated in the NO<sub>x</sub> storage catalyst 16 is started. For this period, firstly the NO<sub>x</sub> concentration downstream from the NO<sub>x</sub> storage catalyst 16 is detected by the NO<sub>x</sub> sensor during a preassigned period of diagnosis and accumulated, and then deducted from a measured or calculated crude NO<sub>x</sub> emission of the engine 10. Secondly, with the aid of known models of the NO<sub>x</sub> storage catalyst 16, and from the crude NO<sub>x</sub> emission, a target mass of absorbed NO<sub>x</sub> is calculated. The target NO<sub>x</sub> mass corresponds maximally to an NO<sub>x</sub> mass that can be absorbed by a fresh NO<sub>x</sub> storage catalyst 16.

In a step S4, it is checked continuously whether the engine 10 is in constant lean operation during the period of diagnosis. In the case of disturbances due to dynamic processes, for example a change in a homogeneous mode or an abrupt shutdown, the target NO<sub>x</sub> mass calculated for the period of diagnosis is especially prone to error, and therefore the monitoring of function is broken off (step S5). Preferably, the period of diagnosis is so determined that it – as already explained – begins with the change in the lean mode (step S3) and continues until a need for regeneration is detected (step S6).

Such a need for regeneration may for example be detected by way of the NO<sub>x</sub> sensor 18 in the form of a threshold emission for NO<sub>x</sub>. Once the need for regeneration is present, a change into the regeneration mode with  $\lambda \leq 1$  is initiated (step S7). Simultaneously, a time counter is started, to determine a duration  $t_{mes}$  for a complete NO<sub>x</sub> regeneration.

From a ratio of the absorbed NO<sub>x</sub> mass found by way of the NO<sub>x</sub> sensor 18 for the NO<sub>x</sub> storage catalyst 18 and the target NO<sub>x</sub> mass, a control value KW<sub>n</sub> is formed in a step S8. If the control value KW<sub>n</sub>, in a step S9, transgresses an upper bound G<sub>no</sub> or a lower bound G<sub>nu</sub>, then there is a defect in the NO<sub>x</sub> sensor 18, and a maintenance signal is produced (step S10). The upper bound GW<sub>o</sub> is usually so chosen that it reflects a ratio of the NO<sub>x</sub> mass found by way of the NO<sub>x</sub> sensor 18 to the target NO<sub>x</sub> mass in a fresh NO<sub>x</sub> storage catalyst 16.

If the control value KW<sub>n</sub> lies between the two bounds G<sub>nu</sub>, G<sub>no</sub>, then in a step S11 it can be checked whether the NO<sub>x</sub> regeneration has been carried out completely. For this purpose for example a lambda probe 22 is suitable,

arranged downstream from the NO<sub>x</sub> storage catalyst 16. Towards the end of the NO<sub>x</sub> regeneration, the value of lambda declines distinctly, and for example by preassignment of a suitable threshold value, a stop signal can be set for the time counter (step S13). If the NO<sub>x</sub> regeneration is discontinued prematurely, the functional monitoring of the NO<sub>x</sub> sensor 18 is broken off here (step S12).

With the aid of the model of the storage catalyst, a target duration  $t_{mod}$  for the NO<sub>x</sub> regeneration is calculated from a measured or calculated state of NO<sub>x</sub> loading. A ratio of the duration  $t_{mes}$  to the target duration  $t_{mod}$  yields a control value  $KW_t$  (step S14). The control value  $KW_t$  is compared with an upper bound  $G_{lo}$  or a lower bound  $G_{tu}$  in a step S15. If the control value  $KW_t$  transgresses the upper bound  $G_{lo}$  or the lower bound  $G_{tu}$ , there is a sensor defect, and a maintenance signal is produced (step S16). If this is not the case, then a new cycle of functional monitoring, beginning with step S3, may be introduced. The upper bound  $G_{lo}$  is again so chosen that it reflects a ratio of the duration  $t_{mes}$  to the target duration  $t_{mod}$  in a fresh NO<sub>x</sub> storage catalyst 16.

Also, sensor plausibility is checked as to whether it does not merely yield a lesser measures fail, for example with poorer storage behavior of the catalyst, or whether at the same time, the measured regeneration time required is reduced to a corresponding extent.